

Constellation-X: Higher Angular Resolution and the ODRM

Martin Elvis

Harvard-Smithsonian Center for Astrophysics

Higher angular resolution for Constellation-X

- **TOTAL: 8 times mass/reflector** = 0.018 km/cm²
 - Opens design parameter space for solutions
 - Similar to XMM-Newton (5"FWHM, 12"HPD, best module)
 - Given Con-X development work, can expect better HPD
- **Wide field of view**
 - carry out ODRM faster
 - Multiple microcalorimeters: optimize ODRM experiments
- **more efficient science program** (2.7 times)
- **Better angular resolution** (2-3"HPD?)
- **Enable new science: larger discovery space**

Two Constellation-X Challenges

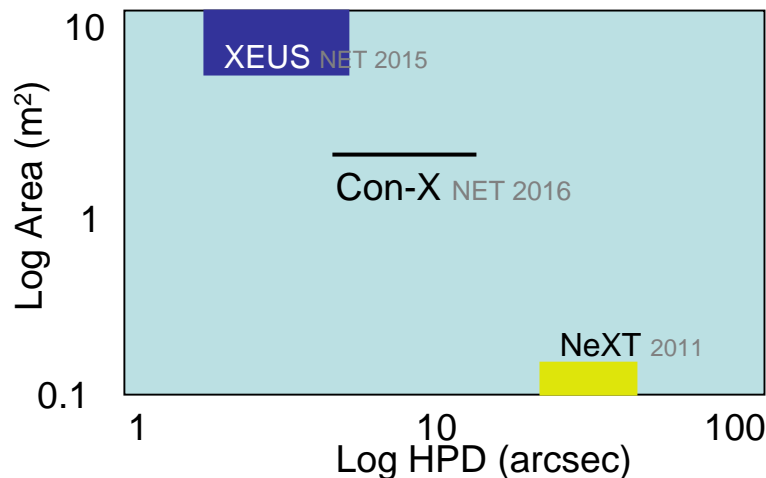
1. *Chandra & XMM-Newton* Science

- Revolution in X-ray astronomy since Con-X architecture was laid down

2. Con-X 'Discovery Space' also claimed by NeXT, XEUS

- High spectral resolution, area;
Moderate spatial resolution
- Similar instruments/spectral, spatial resolution

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.



Response: Higher Spatial Resolution

A greater Con-X Discovery Space

- Only Con-X uses Wolter optics, not conical approximation
 - only Con-X *in principle* has a path to high spatial resolution
- Lesson from *Chandra*:
 - Higher spatial resolution opens up large areas of science
 - 2''HPD science is much broader than 10''HPD science

Science gained from 10'' to 2''

- Quasar jets at high z
- Pulsar wind nebulae
- Starburst galaxy abundances
- Sources 'beyond the X-ray background':
galaxy evolution, high z quasars
- Star formation regions
- Cluster cooling fronts, galaxy interactions
- Cluster-Quasar interaction
- Quiescent supermassive black holes
- Binary black holes
- Gravitational lenses
- Galaxy XRB populations

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

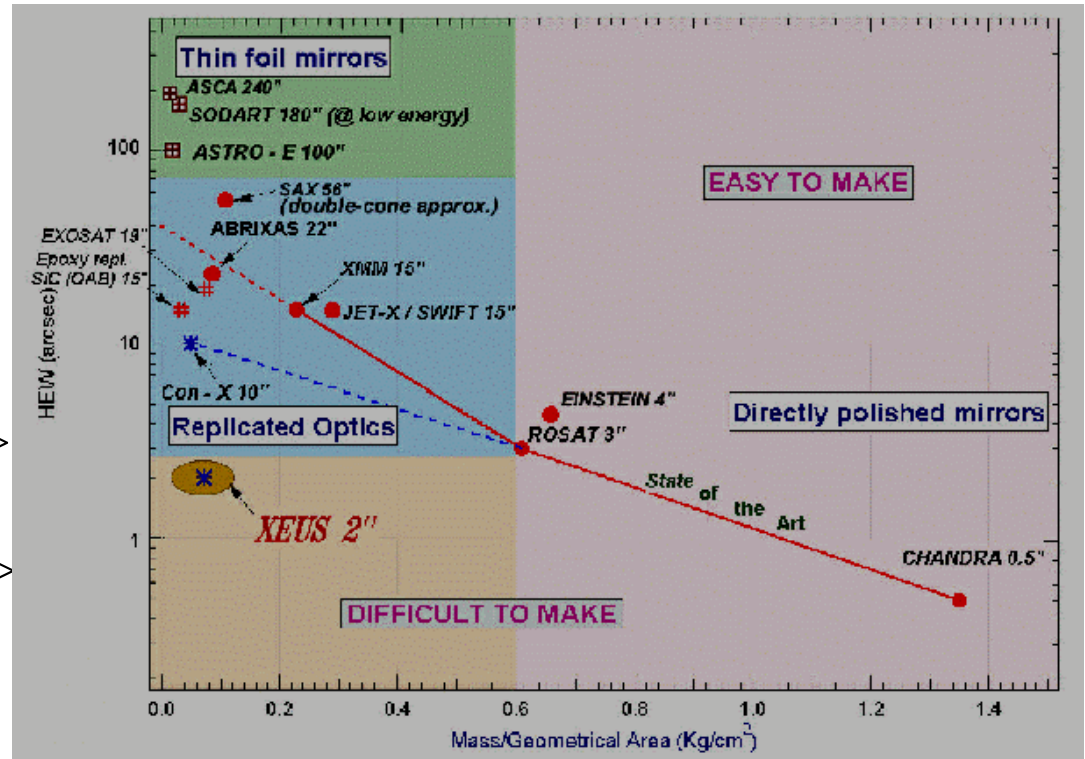
QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

Images are selected
from Chandra press
releases 2002-2004

All essentially inaccessible at 10arcsec HPD

Exploring Higher Angular resolution options

- Mass/area ratio of X-ray mirrors is a major constraint
 - ROSAT: **0.6** kg cm⁻² => 5''HPD (or better)
 - XMM: ~**0.2** kg cm⁻² => 5'' FWHM (best module)
 - *Con-X*: ~**0.02** kg cm⁻² => 15''HPD (requirement)



O. Citterio (Oss. Brera)

- Challenge: *Can we find much more mass/area for the SXT?*

Ground Rule: Same Essential Mission

- TRIP based mission : Same TLRD
 - Academy decadal survey, NASA Roadmap
 - Same Instrumentation
 - Microcalorimeter, Grating, High energy
 - Same ODRM
 - No loss of science goals
 - Same Multiple spacecraft approach
 - No change in focal length
 - Same L2 orbit
 - No XEUS, 50-meter focal length

Goal: Order of Magnitude Gain in mass/ A_{eff} of SXT

- Approach XMM-Newton kg cm⁻²
- How can this be done?
 - Not much room for maneuver, surely?
- 2 main ‘tricks’
- 2nd trick leads to other valuable changes
 - Effect is to increase science efficiency by factor ~ 2.7

1. Ion Engines LEO to L2

- Rocket equation: $\Delta V = v_{ex} \ln(m_i/m_f)$
 - Low v_{ex} of chemical rockets limits m_f
 ΔV from LEO to L2 is 3.2km/s
 - 10 times higher v_{ex} of ion engines **doubles** m_f
 - Numerically factor 2.3, but losses
- Put all of extra mass into SXT mirror assembly:
 - -> **Quadruple SXT mirror assembly mass**
- Factors:
 - Trade TRL of ion engines for TRL of SXT mirrors
 - Acceleration = 0.00001 g
 - 1 year to reach L2 ($t=\Delta V/[NT/M]$, $T=\text{thrust/engine}\sim 60\text{mN}$)
 - 10 standard ion engines [Boeing 601, 702]
 - Extra 20kW solar power needed [c.f. 5.7kW baseline]
 - Use for more telemetry, mirror heating at L2

...next...

2. Take out half the SXT shells

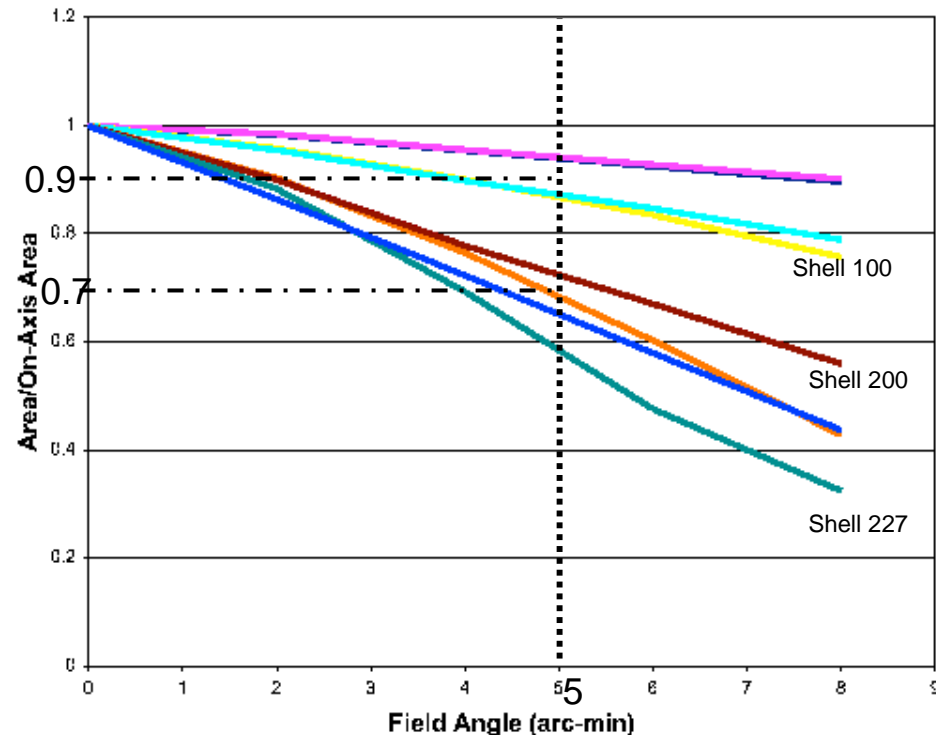


- Gain factor 2 in kg/cm^2
- **Achieved goal of total factor 8 gain in kg/cm^2**
 - Close to XMM mirrors
- Do not lose 1/2 area at all energies:
 - **Be selective:** taking out inner shells saves little weight, so don't.
=> 6.4 keV area unchanged (~4-10 keV estimate)
 - **C-coating** recovers ~40% of 1-4 keV area
 - 50Å coating fills in Au/Ir M-edges (Pareschi & Cotroneo 2003 SPIE 5168...)
 - *sub-keV response* we will get to later

2b: Compensate with larger field of view

- 2 x fov = 4 x solid angle on sky
 - **twice as fast** to observe extended sources, even with 1/2 area.
- SXT vignetting small to 5' at low E ($A(\theta)/A(0) > 0.9$)
- Large vignetting ($A(\theta)/A(0) > 0.7$) at high E
 - due to rays from Parabola missing hyperbola
 - Paul Reid, priv. comm. 2004
- **~10% longer H-segment on inner shells removes vignetting**
 - Minor mass penalty (1-2%?)

Area Ratio($A/A_{\text{on-axis}}$) vs. Field Angle



Quantify effect of field of view on ODRM

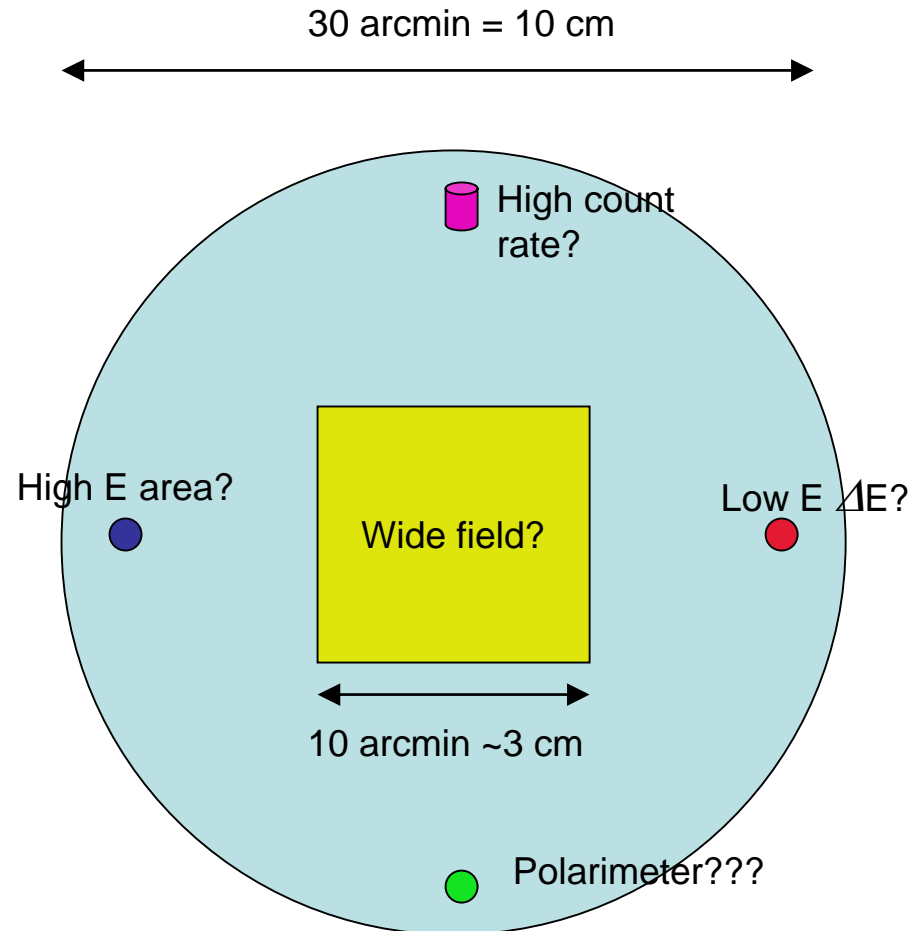
- Assume:
 - 2 x wider fov
 - = 4 x solid angle
 - Could be much larger
- 1/2 effective area
 - Too large a factor
- ODRM:
 - Point sources lose by 2
 - Extended sources/fields gain by 4
- **Overall: 57% gain in science efficiency**
 - Could be larger

Category	Time, Msec	Fov/area	Time*fov/area
Bright AGN	9.0	0.5	4.50
Other AGN	5.5	0.5	2.25
Clusters	10.8	2.0	21.6
Ellipticals/Groups	4.0	2.0	8.0
QSOs & IGM	10.0	0.5	5.0
Faint X-ray background sources	15.0	2.0	30.0
Spirals/starbursts	2.4	2.0	4.8
SNR	9.0	2.0	18.0
X-ray Binaries	3.8	0.5	1.9
Black Hole Candidates	2.0	0.5	1.0
Neutron stars	6.0	0.5	3.0
Stars	9.0	1	9.0
Solar System	0.4	0.5	0.2
TOTAL	86.9		136.25
	[1.0]		[1.57]

3 year program. K. Weaver, priv. comm.

Wider field of view, More efficiency gains

- Non-Wolter prescription: **< 3 arcsec HPD over 30 arcmin field dia.**
 - 2nd generation of WFXT design
 - ASTER-X, Conconi et al. 2003 SPIE 5168...
- 30' dia fov = 10 cm
for 10 meter focal length
- Space for multiple microcalorimeters
- Specialized to experiments
 - > **greater science efficiency**
- Cryostat (dewar, refrigerator, back plane electronics) : **all GFE**
- Need A/D in backplane?
 - Avoid heat loss through many wires
- Cost in calibration time?



Higher Angular Resolution for the SXT

- Now have mass/area ratio needed
- Higher angular resolution is now a reasonable goal
- Cost is area < 1 keV
- Science efficiency of SXT higher
- Further gains are possible...

Science efficiency losses in the ODRM

- All Con-X instruments co-point All the time
 - 3 decade broad bandpass always available
 - Equivalent to simultaneous UV--Far-IR
 - Hard to achieve with separate missions
- But for much of ODRM science does not need full bandpass
 - Equal observing times *mandatory*, regardless of science needs
 - E.g. HXT/SXT deep surveys
 - HXT fov inherently small: inefficient rastering of SXT field
 - often 1 instrument is effectively idle, sometimes 2
 - Loss of science efficiency
 - Calibration of 3 instruments is sequential
 - Different calibration targets in each energy range
 - SXT is idle while RGA, HXT being calibrated (small, 4%, loss)

Quantify ODRM Science Efficiency

Category	Time Msec	SXT- XMS	SXT- RGA	HXT	Instrument Utilization	Util x time
Bright AGN	9.0	Prime	Prime	Prime	1	9.0
Other AGN	5.5	Prime	2nd	2nd	2/3	3.7
Clusters	10.8	Prime	---	----	1/3	3.6
Ellipticals/Groups	4.0	Prime	---	---	1/3	1.3
QSOs & IGM	10.0	2nd	Prime	---	1/2	5.0
Faint X-ray background sources	15.0	Prime	---	2nd	1/2	7.5
Spirals/starbursts	2.4	Prime	---	2nd	1/2	1.2
SNR	9.0	Prime	---	2nd	1/2	4.5
X-ray Binaries	3.8	Prime	Prime	Prime	1	3.8
Black Hole Candidates	2.0	Prime	Prime	Prime	1	2.0
Neutron stars	6.0	Prime	Prime	2nd	2/3	4.0
Stars	9.0	2nd	2nd	---	1/2	4.5
Solar System	0.4	2nd	2nd	---	1/2	0.2
TOTAL (3 years)	86.9					50.3
	[1.0]					[0.58]

Utilization: prime = 1.0; 2nd = 0.5, --- = 0.0

Solution: Separate instruments on separate spacecraft

- 4 Spacecraft:
 - #1, #2 = SXT+XMS (retain redundancy, lower risk)
 - #3 = HXT
 - #4 = ‘LEST’ (Low Energy Spectroscopic Telescope): Gratings+CCD readout
- 70% gain in instrument utilization
 - Do ODRM faster: more science
- Common mission TAC & OCC enables:
 - Co-pointing when science requires (by proposal)
 - Independent otherwise for greater science efficiency
 - Parallel calibrations
- Keeps ‘constellation’ concept
- Gratings on separate mirror
 - Recover ‘lost’ factor 2 in sub-keV area

Low Energy Spectroscopic Telescope

- 0.05keV - 1keV (0.87 keV?) 5"HPD mirror
- Out of plane Gratings -> $R=5000$ spectroscopy
 - Reaches 'thermal limit' (Elvis 2002): **enables new science**
- Large graze angles
 - 3 meter focal length -> 3 x more area/kg
 - Nickel reflectivity gains factor 2 in A_{eff} $E < 0.87$ keV
 - Small, low mass [1.3m dia, $M=153\text{kg}$] => $A_{\text{eff}}(\text{mirror}) = 5,000 \text{ cm}^2$
 - More stable segments -> higher resolution?
 - Small moment of inertia -> rapid slews (1min?) -> **enables new science**
- Remarkable similarity to *Pharos* mission concept:
 - GRB afterglows for cosmology
 - 2 small GRB finding, positioning instruments needed
 - See *astro-ph/0303444* (Elvis, Fiore, Nicastro et al.)

Summary:

Higher angular resolution for Constellation-X

1. Ion engines to L2: quadruple SXT mirror mass
2. Selectively remove SXT shells: double kg/cm²
 - **TOTAL: 8 times mass/reflector** = 0.018 kg/cm²
 - Similar to XMM-Newton
 - Given Con-X development work, better HPD plausible
3. Wide field of view:
 - carry out ODRM faster (factor 1.6)
 - Multiple microcalorimeters: optimize ODRM experiments
4. Instrument specialized spacecraft
 - Carry out ODRM faster (factor 1.7)
 - Factor 2.7 times more efficient science use
 - Plus better angular resolution (2-3"HPD?)
 - Enables New Science: Larger Discovery Space
 - Answers Challenges to Constellation-X

What if XEUS merger, 50m focal length?

1. *Ion engines to L2: doubles mass at L2*

1. even more area; 2. more on-orbit propellant; 3. cheaper launch
use for continuous thrusting to maintain s/c alignment

2. *Selectively remove SXT shells: double kg/cm²*

No need in XEUS case - light mirror already.

3. *Wide field of view*

XEUS conical, but good PSF field is likely inherently large.
At 50m focal length large detectors needed to cover field.
Multiple microcalorimeters still useful.

4. *Instrument specialized spacecraft*

50m Con-X: no baffling problems; space for s/c in center;
can drop outer shells

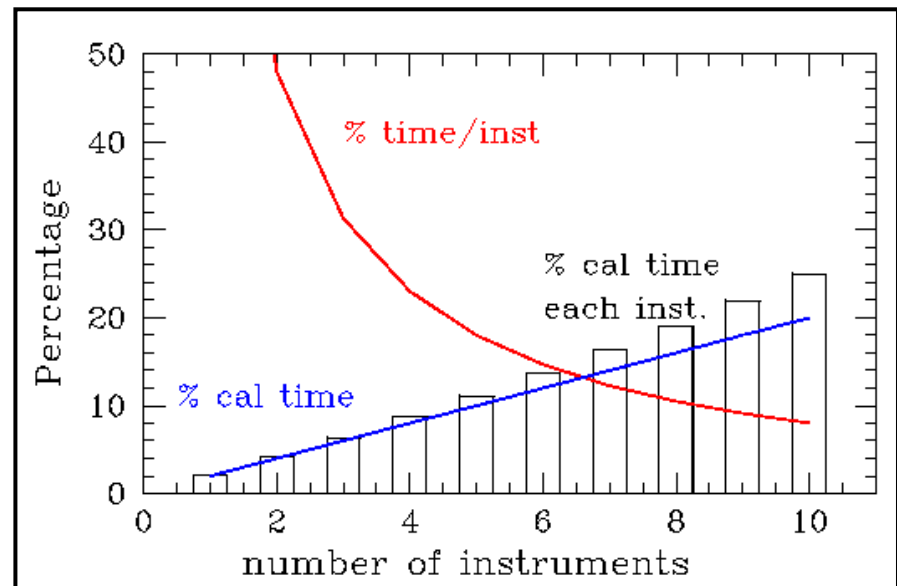
XEUS: easing of calibration problem (>6 instruments)

New science (e.g. GRB afterglows for cosmology)

More observations/year: wider community (*2 ksec possible?*)

Calibration cost of multiple instruments

- ‘Christmas tree’: many instruments on 1 spacecraft
 - Has a cost in Calibration time
 - **Useful limit 5-6 instruments**
-
- Derived as follows:
 - ACIS takes ~2% of *Chandra* observing time (0.41Ms, cycle 5, excluding CTI data)
 - Assume typical of advanced instruments
 - Assume each instrument needs separate calibration (targets)
 - Also FTE needs to analyze cal. data



Alternate way to do Relativistic Fe-K Lines

- Need high count rate
 - Can *only* use brightest AGNs (~ 1 mCrab $\sim 10^{-11}$ erg cm $^{-2}$ s $^{-1}$, 2-10 keV)
 - Angular resolution unimportant (~ 1 arcmin will do)
- Need lots of observing time: large share of mission
 - Monitor AGN states
 - Transient features
- Con-X SXT area barely sufficient
- Solution: **Microchannel plate mirrors** (ESA/Leicester development)
 - 100 times area/mass of foils
- MIDEX class mission possible
- Remarkably similar to mission concept for *Extreme Physics Explorer* (Elvis astro-ph/0403554)

